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THE WHIRLING SPEED OF THE INDUCTION MOTORS AND UNBALANCED MAGNETIC PULL (UMP)-A REVIEW

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ABSTRACT

The evaluation of whirling speed and related whirling motion of the rotating elements (such as shafts) is one of the crucial problems to be addressed by design as well as maintenance engineers. This paper reviews on whirling speed of electrical machines, precisely, an induction motor and an introduction to phenomenon called unbalanced magnetic pull (UMP). In an induction motor, the shaft- rotor assembly is the actual physical rotating element. For this rotating element, at a particular speed, the the natural frequency of transverse vibration is equal to the frequency due to operating speed, then that speed is called as 'critical speed' or 'whirling speed' of that particular rotating element. The UMP incorporates the facts as; the electromagnetic forces existing between stator and rotor are produced due to electromagnetic fields in the electric machines' air gap. This total force exerted on the rotor by virtue of its (i.e. rotor's) eccentric position is termed as 'unbalanced magnetic pull (UMP)'.

KEYWORDS: Whirling Speed, Critical Speed & Unbalanced Magnetic Pull (UMP)

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Original Article

INTRODUCTION

For a rotating shaft- rotor assembly, there is a speed at which, for any initial deflection, the centripetal force and the elastic restoring force are equal. This is the point at which the value of deflection raises drastically and the assembly is said to "whirl". Above and below this speed, the whirling effect is reduced at much extent. This critical speed (whirling speed) is dependent on the material and dimensions of shaft-rotor assembly, various loads and dimensions and specifications of special features as key. The whirling speed is the same as the frequency of traverse vibrations. Various factors such as total mass of assembly, unbalance of the mass with respect to the axis of rotation, stiffness of the aggregate assembly and its supports and attached parts play a key role in determination of magnitude of deflection. The whirling of shaft and its motion comes under self- excited category which is elaborated further in discussion point titled evaluation of whirling speed.

In corroboration of the above explanation, in case of the rotating shafts, there is a deflection during rotation due to self-weight only, even though there is an absence of any external load. The aggregate weight of a shaft and its mountings can give the existence to the deflection that will cause resonant vibration at some speed. The rotating shafts always have a tendency to oscillate transversely. The centrifugal force occurring due to the shaft being out of balance will provoke the shaft to vibrate. When the speed of rotation of shaft equals the natural frequency of transverse oscillation, these vibrations become violent and this phenomenon summarizes as the whirling of the shaft.

The electromagnetic forces between stator and rotor are induced due to the electromagnetic field existing in the

air gap of an electrical machine like an induction motor. Over the shortest air gap, the rotor position which is eccentric produces an unbalanced magnetic pull (UMP). The additional static load, which influences the bearing wear, is induced by one component of such eccentricity. The electromagnetic and mechanical system is coupled via modes of flexural vibration of the shaft by virtue of eccentricity force. The critical speeds and natural frequencies related to these flexural modes are decreased by this interaction. Additional velocity-dependent forces induced by the electromechanical interaction may dampen the flexural rotor vibrations or give a source of self-excited vibrations. The most undesirable case may be the catastrophic failure due to stator- rotor contact during operation due to roto-dynamic instability caused by electromechanical interaction.

IMPORTANT TERMINOLOGIES

Whirling Speed

In the field of rotor dynamics, the theoretical angular velocity that eventually excites the natural frequency of a rotating element or object, such as a shaft, gear, lead screw or propeller etc. is termed as whirling speed.

The system vibrations increase dramatically as the object begins to resonate due to attaining of object's natural frequency by virtue of speed of rotation. The resulting resonance occurs regardless of orientation. When the numerical value of the natural vibration is equal to the rotational speed, then such speed is referred as whirling speed or critical speed.

In general, it is necessary as well as desired to evaluate the whirling speed of a rotating shaft in order to avoid issues with design and maintenance.

Whirling Speed Analysis

The whirling speed analysis incorporates the determination and calculation of undamped critical speeds, associated energy distribution (kinetic and potential), mode shapes and modal stress. If the bearing or support is not isotropic then the system is assumed to be isotropic and the designer can select the direction associated to the bearing stiffness to be used in the analysis purpose. The value of bearing stiffness at the peak speed is used for multiple bearing coefficients which are speed dependent. In the Critical Speed Analysis, along with other aspects, the flexible support effect is also considered primarily.

Unbalanced Magnetic Pull (UMP)

Electrical machines having rotating elements have a small air gap between the stator and rotor. The electromagnetic forces are induced due to magnetic fields operating in air gap, which will further act on structure of machine. It is expected that the air gap between stator and rotor should be same along the complete circumference and the electromagnetic forces are neutralized cancelling each other. But it is very difficult or rather impossible to maintain the thickness of air gap constant along the complete circumference, in fact, the air gap thickness is not constant along a whole circumference. It can be elaborated with an example as, there is a static or dynamic eccentricity due to the geometric deviation of the stator and rotor from ideal cylindrical shape and hence the cancelling of electromagnetic forces by each other is not possible and the resulting electromagnetic force is called the unbalanced magnetic pull (UMP).

LITERATURE SURVEY

A proper literature survey is done in order to understand the research carried out with till date and various methodologies adapted by researchers and is presented herewith.

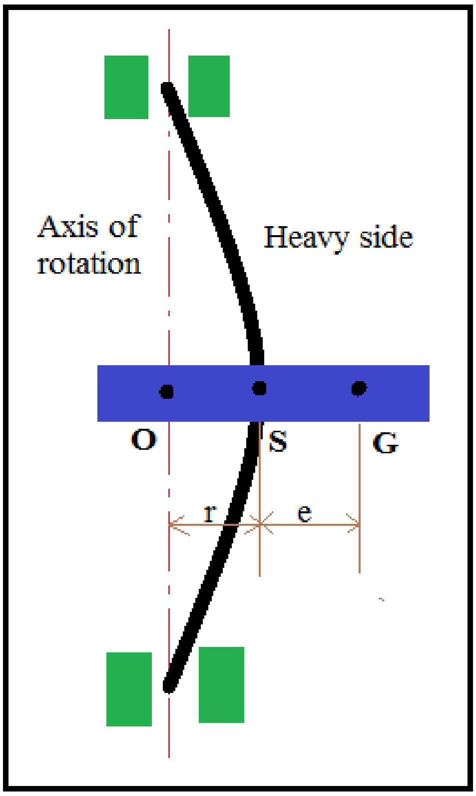

Figure 1: Whirling of Shaft [1].

Ziyuan Huang et al., [1] mentioned that, it must be treated as an initial approach to evaluate the critical speed of the rotating shaft. During operation, when the rotor attains the critical speed, violent vibrations are generated and the respective deflection is also very large. The sensitivity of rotor system can be identified to every design aspect with the help of analysis of critical speed. By virtue of this, the designers are enabled to modify the critical speeds of rotor in a quick and easy manner.

Typical whirling process is as shown in figure. 1, where

- 'O' is line of bearings.
- 'S' is geometric centre.
- 'G' is the centre of mass.

At a certain speed, resonant vibrations are generated due to deflection caused by the unbalanced mass of an object which is rotating, termed as whirling speed. For a shaft, having a rotor or without a rotor, the centre of gravity and axis of rotation of shaft usually doesn't coincide as the centre of gravity is normally displaced from the axis of rotation, although the displacement may be very small. This displacement of C.G. may be due to one or more of the following causes:

- Eccentricity mounting of the rotor on the shaft.
- Lack of straightness of the shaft.
- Bending of shaft under the action of gravity in case of horizontal shaft.
- Non-homogeneous rotor material.
- Unbalance magnetic pull in case of electrical machinery.

Raj Mistry et al., [2] discussed that, various case studies show that, there are significant changes in performance for slightest changes in parameters of motor. Hence, it is expected that at least 15% separation margin(SM) should be there among operating speed and critical speed. A design with separation margin above 15% can be taken to below separation margin limits by change in clearance which is apparently minor in magnitude. A minute change in value of clearance can affect the roto-dynamic performance. In similar concern, the wear of bearing journals during operating life could be a reason for exacerbated roto-dynamic performance and resulting variation in critical speed.

Ankit J. Desai et al., [3] mentioned that, self-excited motion (with reference to self-excited vibration) is the motion in where the exciting forces and inducing motion are controlled by the motion itself. And the whirling of shaft and its motion fall under this particular category. The unbalance response and critical speeds are the most predominantly enquired and predicted rotor- bearing system characteristics which are dynamic in nature.

C. W. Bert et al., [4] discussed whirling of the composite material driveshaft. The most popular composite material for shaft is Graphite-Epoxy. With reference to critical speed, the bending, twisting and shear deformation can be studied more precisely. For effective results, Bresse-Timoshenko model can be used.

Erik Swanson et al., [5] explained that, the machine is said to have surpassed the whirling speed as a distinct peak appears on response versus speed graph, which is caused by the rotor with appropriate unbalance unbalanced distribution have excited the respective undamped natural frequency. Based on this, it can be stated as “peak response” speeds are whirling speeds. Considering a structural case, the speeds coinciding with damped natural frequency are termed as ‘ damped critical speeds’ and numerically, critical speeds are way distinct from these with reference to definitions by API specification. They become considerably different for increasing levels of damping while they are fairly close for lighter damping.

Chun-Do Kim et al., [6] showed that, for a rotating cylindrical hollow shaft with circular cross-section having variety of laminated composite materials which are layered accordingly, the thin and thick shell theory approach can be used as an efficient tool to determine whirling speeds. The composite materials may be orthotropic, monoclinic, isotropic or transversely isotropic as per requirement. The Donnell’s theory is inefficient for long shaft among multiple available shell theories. In similar context, the effect of transverse shear moduli on the whirling speeds are negligible for very thin walled drive shafts.

E. Downham [7], Showed that, for the naturally vibrating non-rotating system, the effect of inertia couples occurring due to the rotor, on the forms of deflection for the whirling system, can be experimentally obtained and these are compared with the forms of deflection, which are obtained by virtue of static load at the rotor’s particular point of attachment of non-rotating system. For rotor inertia of different amounts, the whirling speeds and natural frequencies of non-rotating system were calculated and these results are compared with the derived values of natural frequencies and critical speeds. A worthy and decent agreement can be obtained by comparing measured and calculated whirling speeds.

Martin Donát [8] states that, the motors operating close to first flexural critical speed have a much higher significance of the electro mechanical interaction. In constant speed operation, this critical speed is primarily avoided because of excessive vibrations and also passed as early as possible speed-up and run-down transient situation. But, this is not the same case all the time. Also, the adjustable speed drives have increased their application area with requirement of operating close to critical speeds as much as possible.

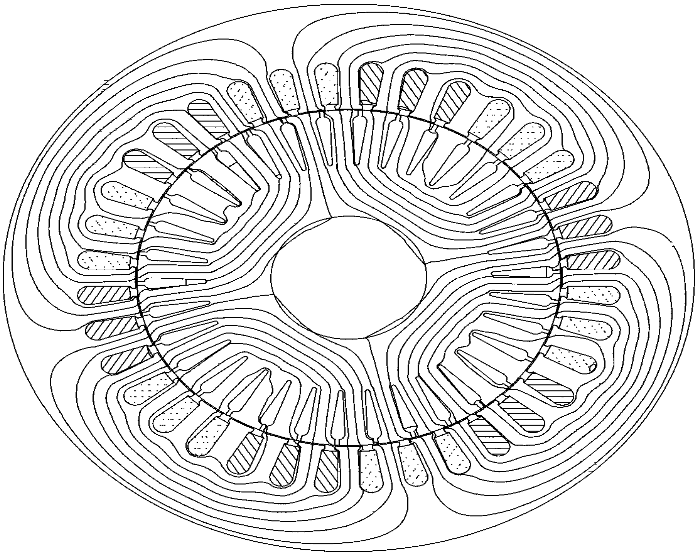

Figure 2: The Magnetic Field of an Induction Motor during the Rated Operation. The Rotor is in Concentric Position [10].

Timo P. Holopainen [9] mentioned that, for transient operation, the electromechanical interactions can be modelled and described with a simple but robust model which may greatly enhance the vibration control of high-power motors and roto-dynamic design capabilities.

Felix Boy et al., [10] discussed, unbalanced magnetic pull (UMP) is one of the most crucial magnetic forces for study, research and design of synchronous or induction machines. The eccentricity of rotor tend to spatially change the air gap which results in asymmetry in magnetic field, this asymmetry is the reason for UMP. As per classical approach, the action of UMP is radially outward in the direction of minimal air gap and it reduces rotor’s natural frequency by acting against restoring force of shaft.

Figure 2 shows an example, the electromagnetic field of an induction motor during operation.

The electro magnetic field around the rotor in the cylindrical can be given a division into the spatial harmonic components. The fundamental component is required for torque generation; a fundamental component is the component which is the strongest and main one. The number of pole-pairs of the machine, (p), is equal to the order of the fundamental component. Two additional field components are produced by virtue of rotor position which is eccentric with the fundamental field component. The order of the fundamental component and order of these additional field components differ by one represented as $p\pm1$. These additional field components and the fundamental field together produce the major part of eccentricity force. The rotor cage’s equalizing currents make this description complicated to a particular extent. The eccentric rotor position and the fundamental field induce harmonic currents; also the total eccentric force exerted on the rotor can be decreased by inducing same field components by them.

FINDINGS OF THE LITERATURE SURVEY

- Critical speed by virtue of resonance generates violent vibrations in the shaft.
- In the study and analysis of critical speed, eccentricity of rotor mounting on shaft play a vital role especially when electrical motor is under study.

- The cumulative mass of the shaft and parts attached to it, shaft stiffness, damping provided to system and mass unbalance with reference to the axis of rotation are the key factors which influence the magnitude of shaft deflection.
- Proper and precise identification of critical speed is necessary in order to avoid shaft bearing assembly failure.
- The action of UMP is radially outward in the direction of the minimal air gap and it reduces the rotor's natural frequency by acting against restoring force of the shaft.
- The eccentricity in positioning the rotor is the prime reason for the uneven air gap.
- The numeric value of UMP plays a very crucial and integral role in the calculation of accurate whirling speed in electrical motors.

OBJECTIVES OF STUDY

This paper gives a brief idea about whirling speed of induction motors and its effect on the overall stability and performance of the system. The phenomenon titled 'unbalanced magnetic pull (UMP)' is also reviewed and elaborated along with its impact and involvement in the scenario of whirling speed of induction motor.

This paper will also help in research and analysis work aiming evaluation of whirling speed of an induction motor.

CONCLUSIONS

This paper summarizes that attainment of whirling speed by an induction motor during operation causes excessive violent vibrations. For secure operation and ensuring stability, it is desired, at the rotor design stage of the high-speed motor, the rated speed of the particular motor and the whirling speed should have a considerable difference in value. Also unbalanced magnetic pull (UMP) which is caused by uneven air gap should be considered as one of the primary design parameter as it serves for system imbalance. So, proper compensative action for UMP establishes proper operation of system with intended efficiency.

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